Effects of HD-tDCS on speech fluency in adults who stutter: a randomized controlled trial

Emily O. Garnett[1], Ho Ming Chow[2], Megan Sheppard[3], Gregory Spray[3], & Soo-Eun Chang[1]
[1]University of Michigan, [2]University of Delaware, [3]Michigan State University

Abstract

There is accumulating support for the role of the basal ganglia thalamocortical (BGTC) network in stuttering, in particular in connections between the basal ganglia, supplementary motor area (SMA), and ventral premotor cortex (vPMC)[1]. In the GODIVA model[2], these regions are crucial for fluent speech production which requires precisely timed movements in order to sequence and produce speech sounds. Regions within the BGTC are critical in planning complex movement routines, including speech, that are *internally* timed and initiated, rather than in response to external cues[3]. People who stutter show difficulty with tasks that require such precisely timed movements in speech and non-speech tasks involving rhythm and timing, results that are corroborated by attenuated functional connectivity among these BGTC regions[4,5,6]. When people who stutter speak with an external rhythm (e.g., metronome-timed speech or choral speech), their stuttering is temporarily drastically reduced or even eliminated[7]. Such fluency-inducing conditions are also associated with 'normalized' brain activation patterns in posterior auditory regions (e.g., posterior superior temporal gyrus [STG]) similar to fluent speakers[8,9].

Treatment with these techniques is inadequate as changes in speech fluency are temporary[10] and the benefits outweighed by reduction in naturalness. Neuromodulation techniques such as transcranial direct current stimulation (tDCS), may offer new insights into stuttering treatment. A recent study paired anodal tDCS targeting left inferior frontal gyrus (IFG) with fluency induced speech in 30 adults who stutter who received either sham or active tDCS for 20 minutes on 5 consecutive days[11]. Active tDCS significantly decreased stuttering 1 week after treatment compared to sham. Another study found cathodal tDCS applied to right Broca's area also decreased stuttering[12]. Recently, we reported results of single session (1.5mA, 20 minutes) of anodal or sham stimulation targeting left SMA during fluency-inducing speech in 14 adults who stutter[13]. Speech samples were collected before and after stimulation. During the reading portion, stuttering significantly decreased after both active and sham tDCS. Active stimulation had a greater effect on %SLD, resulting in a decrease of 3.55% compared to 2.86% after sham, although this was not statistically significant and may not represent a clinically meaningful change. Thus, the present study tested whether combining fluency inducing conditions with tDCS delivered intensively over five consecutive days could lead to immediate and long-term (1 month) improvements in speech fluency, similar to previous studies[11]. Because research has shown 'normalized' brain activation in pSTG during fluency-induced speech, and after intensive training, we hypothesized that targeting left pSTG with brain stimulation will augment these effects beyond that of training alone. This region is also structurally connected to the left IFG which was targeted in previous studies[11].

Methods

In this randomized double-blind study (NCT03437512) participants completed 5 consecutive days of stimulation while reading with a metronome. Study design is shown in Figure 1. They were assigned to the anodal (2mA, 20 min) or sham (2mA, 30 sec) stimulation group using a minimization procedure, which minimizes the imbalances between groups on several factors and is appropriate for clinical trials with low subject numbers. Groups were balanced for sex, age, stuttering severity, handedness, and measures of working memory and musical training. Baseline stuttering severity (%SLD); Stuttering Severity Instrument score, [SSI-4]), Naturalness (NAT; 1-9 rating, 1=most natural), and OASES (Overall Assessment of the Speakers' Experience with Stuttering) scores were collected.

Results

Nineteen AWS (3F) have completed the study. Primary measures (%SLD, SSI-4) and secondary measures (naturalness rating, OASES) decreased significantly in all participants from pre- to post-testing (Table 1). Data collection ends in early 2020 at which time the study staff will be unblinded to group assignment (anodal, sham) and effects of stimulation can be assessed. We expect active stimulation to

improve speech fluency to a greater degree than training alone (sham) and that improvement will remain at 1-month follow up.

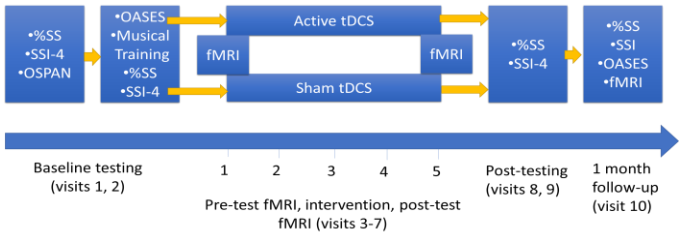

Figure 1. Study design. Following baseline, participants are assigned to either active or sham stimulation group. Study procedures/schedule are otherwise the same for each group.

	Age	EDU	%SLD Pre	%SLD post	SSI Pre	SSI Post	OASES Pre	OASES Post	NAT Pre	NAT Post
Mean	25.97	16.26	8.18	6.48	25.61	19.68	2.61	2.49	5.39	3.89
SD	7.00	2.27	7.49	5.42	7.86	7.46	0.68	0.69	2.01	1.94
% Decrease	-	-	20.77		23.12		4.40		27.80	
p	-	-	0.0201		0.0001		0.0027		0.0001	

Table 1. Participant demographics pre and post stimulation (not separated by stimulation group; *p* value from paired t-tests; EDU = years of education; SD = standard deviation), all other abbreviations in text).

References

1. Civier, O., Bullock, D., Max, L., & Guenther, F. H. (2013). Computational modeling of stuttering caused by impairments in a basal ganglia thalamo-cortical circuit involved in syllable selection and initiation. *Brain and Language*, *126*(3), 263-278.
2. Bohland, J. W., Bullock, D., & Guenther, F. H. (2010). Neural representations and mechanisms for the performance of simple speech sequences. *Journal of Cognitive Neuroscience*, *22*(7), 1504-1529.
3. Packman, A., Code, C., & Onslow, M. (2007). On the cause of stuttering: Integrating theory with brain and behavioral research. *Journal of Neurolinguistics*, *20*(5), 353-362.
4. Chang, S. E., Chow, H. M., Wieland, E. A., & McAuley, J. D. (2016). Relation between functional connectivity and rhythm discrimination in children who do and do not stutter. *NeuroImage: Clinical*, *12*, 442-450.
5. Chang, S. E., & Zhu, D. C. (2013). Neural network connectivity differences in children who stutter. *Brain*, *136*(12), 3709-3726.
6. Wieland, E. A., McAuley, J. D., Dilley, L. C., & Chang, S. E. (2015). Evidence for a rhythm perception deficit in children who stutter. *Brain and Language*, *144*, 26-34.
7. Park, J., & Logan, K. J. (2015). The role of temporal speech cues in facilitating the fluency of adults who stutter. *Journal of Fluency Disorders*, *46*, 41-55.
8. Toyomura, A., Fujii, T., & Kuriki, S. (2011). Effect of external auditory pacing on the neural activity of stuttering speakers. *NeuroImage*, *57*(4), 1507-1516.
9. Toyomura, A., Fujii, T., & Kuriki, S. (2015). Effect of an 8-week practice of externally triggered speech on basal ganglia activity of stuttering and fluent speakers. *NeurIimage*, *109*, 458-468.
10. Kell, C. A., Neumann, K., von Kriegstein, K., Posenenske, C., von Gudenberg, A. W., Euler, H., & Giraud, A. L. (2009). How the brain repairs stuttering. *Brain*, *132*(10), 2747-2760.
11. Chesters, J., Möttönen, R., & Watkins, K. E. (2018). Transcranial direct current stimulation over left inferior frontal cortex improves speech fluency in adults who stutter. *Brain*, *141*(4), 1161-1171.
12. Yada, Y., Tomisato, S., & Hashimoto, R. I. (2019). Online cathodal transcranial direct current stimulation to the right homologue of Broca's area improves speech fluency in people who stutter. *Psychiatry and Clinical Neurosciences*, *73*(2), 63-69.
13. Garnett, E. O., Chow, H. M., Choo, A. L., & Chang, S. E. (2019). Stuttering severity modulates effects of non-invasive brain stimulation in adults who stutter. *Frontiers in Human Neuroscience*, *13*, 411.